Cobalt-chrome Rods in Spine Surgery: What Is the Risk of a Battery Effect?

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Sternal implants—including screws, rods, and plates—are manufactured using stainless steel, pure titanium, and titanium alloys. Each of these has its own advantages and disadvantages.

For example, advantages of titanium include its biocompatibility and the ability to do spinal imaging with magnetic resonance imaging without loss of signal secondary to metal artifact. Its disadvantages include decreased material stiffness, strength, and hardness. Titanium is prone to notching after bending deformation or at attachment sites to pedicle screws, which makes it more subject to fatigue failure.

Newer implants made from cobalt-chrome (Co-Cr) alloys are stiffer and have harder surfaces that may provide advantages in deformity and trauma care. The stiffness of metals is estimated by Young’s modulus (ratio of stress along an axis over the strain along that axis) and, by that measure, wrought Co-Cr is approximately 3 times stiffer than titanium alloy. Stainless steel is a balance between these two materials and has a Young’s modulus about twice that of titanium (Table 1).

**The battery effect**

To optimize function, some implant systems use several metals for different components. For example, Co-Cr rods may attach to titanium alloy screw heads, or Co-Cr rods and screw heads may attach to titanium alloy screw shanks.

This matching of dissimilar metals raises the concern of galvanic (bimetal) corrosion, also known as the battery effect. The purpose of this review is to discuss the scientific implications when using dissimilar metals in spinal constructs.

An electrochemical effect occurs when two dissimilar metals, also known as a “couple,” are placed in an ionic bath. An electric potential is created and ions flow from the anodic metal, which is more resistant to corrosion and oxidation (more noble and less reactive), to the cathode metal (less noble and more reactive). The more resistant metal of the pair will undergo less corrosion while the less resistant metal will undergo greater corrosion.

The strength of the effect is proportional to the difference in the electrochemical properties of the metals, called the “anodic index,” and can be measured by the electromotive force. The electromotive force is the maximum potential difference between two dissimilar metal electrodes in a galvanic cell, as shown in Table 1. Another method to report this is to compare the metals to a noble material such as gold.

Galvanic corrosion occurs when certain conditions are met and results in dissolution of the metal. In medical devices, galvanic corrosion can lead to pain, inflammatory responses, metallosis, and device failure. For this reason, bimetallic systems designed to be used in corrosive environments should have an anodic index of 0.15 or less.

**Spinal implants**

Recently, the use of dissimilar metals has increased in orthopaedic and spinal implants. Corrosion at the interface of dissimilar metals has been extensively studied in hip arthroplasty implants, where it can be seen at the junction of the Co-Cr head and the trunnion of the titanium alloy femoral stem. Less attention has been paid to the possibility of corrosion between Co-Cr rods attached to titanium alloy or stainless steel pedicle screws in the spine.

For galvanic corrosion to occur, the following three conditions must be met: dissimilar metals, electrochemical contact, and a path for ion exchange. All three conditions are present when medical devices are placed in the body.

Galvanic corrosion may be minimized by lessening the impact of environmental factors through a process called passivation. During this process, the surface of the implant is coated with a shielding layer, usually by formation of oxides, which will resist ion exchange. Passivation can be performed during the manufacturing process, but with some metals, it also occurs naturally in vivo environments. Titanium and Co-Cr alloys are excellent at self-passivation in vivo, whereas stainless steel requires surface treatment prior to implantation.

Motion or wear between the metals may remove the passivated surface, increasing the risk of both galvanic and fretting corrosion. Although coating the surfaces with polymers or other techniques may improve the stability of the passivation layer and help avoid electrochemical effects, coatings may also shift the main corrosion mechanism to crevice and fretting. Coatings that produce harder (oxide or ceramic-like) surfaces may wear, resulting in debris that can cause or increase third-body abrasive wear.

The question regarding the advisability of using a Co-Cr–titanium couple in spine surgery was answered in the affirmative decades ago. Kummer and Rose found that titanium alloy–Co-Cr couples formed a stable passivation surface and reduced electromotive current over time, while stainless steel–Co-Cr couples became more unstable and had increased current and corrosion over time.

More recently, Serhan and colleagues compared corrosion of stainless steel, titanium alloy, and stainless steel–titanium alloy spinal instrumentation couples that were exposed to saline under 5 million cyclical loading. The stainless steel couple was found to have more corrosion than either the titanium alloy or the stainless steel–titanium alloy couple.

**Osteolysis**

Osteolasts will respond to electrical fields and therefore may respond to electrochemical potentials around implants. This may have an untoward effect on spinal fusion or lead to osteolysis.

Denaro and colleagues determined the in-vitro electrochemical potential around a failed spinal explant with osteolysis. They then applied the same electromagnetic force to osteolasts. Explanted titanium alloy screws formed a stable passivated surface and had a six-fold higher passivation current density than pure titanium. Application of the electromagnetic force also decreased cell proliferation by 10 percent to 25 percent for up to 14 days. As a result, the researchers concluded that electrochemical effects can inhibit osteoblastic activity at the bone-screw interface.

The use of titanium alloy screws and Co-Cr rods appears to be justified from explant analysis and in vitro electrochemical experiments. However, clinical data are lacking. The use of Co-Cr rods and stainless steel screws should be avoided because significant corrosion has been documented in these couples. Corrosive wear should always be considered in patients who have dissimilar metal couples and unexplained pain or swelling.

References for the studies cited in this article can be found in the online version, available at www.aaosnow.org

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